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Solar Cycle Influence on Super Geomagnetic Storm (Dst≤-300nT): A Quarter-Day Analysis

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A comprehensive statistical analysis of Super Geomagnetic Storms (SGMS), characterized by Dst ≤ -300nT, reveals a pronounced diurnal asymmetry in their occurrence. The first (01-06 UT) and fourth (19-24 UT) quarters of day exhibit a significantly higher frequency of SGMS, accounting for approximately 82.12% of events, whereas the second (07-12 UT) and third (13-18 UT) quarters of day show a substantially lower occurrence rate of 16.1%. This disparity indicates a strong preference for SGMS to occur during the first and fourth quarters. Further examination of SGMS within the optimal time interval (19 UT - 06 UT) (including first and fourth quarters of day) across various solar cycles reveals occurrence rates of 82.5% (SC20), 83.3% (SC21), 100% (SC22), and 74% (SC23). These findings highlight the non-uniform distribution of SGMS throughout the day and their variability across solar cycles, with the time interval around the solar cycle peak being particularly susceptible. Consequently, tasks involving magnetic fields (TIMF), such as satellite launching, magnetic surveys, GPS, power systems, and radio communication, should exercise extreme caution during this time interval to mitigate potential errors.

Keywords: SGMS, SSN, TIMF.

1. Introduction

The Sun is a magnetically active star. When the SSN (Sunspot numbers) changes, the Earth's magnetic field is also disturbed. When the time interval in the solar cycle from 01UT to 24 UT is divided into four parts of 06 hours each, then SGMS (Dst≤-300nT) are most commonly produced between 19 UT to 06 UT (first + fourth quarter). Gonzalez W.D. et al.[2] this study provided connection between solar cycles and intense geomagnetic storm from 1965 to 1985. G. Le et al. [7] analyze solar cycle distribution of great geomagnetic storm after statistical analysis from 1957 to 2005 it was shown that 83% of great geomagnetic storm occur two year before and three year after the solar peak. Echer E. el at. [1] studied intense geomagnetic storm and analyzed their relation with interplanetary parameter for space weather forecasting. Gonzalez et al. [3] examine the distribution of super geomagnetic storm throughout solar cycle, the summary of this paper suggests that super geomagnetic storms occur in all phases of the solar cycle but are more frequent around the solar maximum and during initial descending phase. Le G. et al. [8] statistical analysis of the major geomagnetic storm from

1957 to 2006 the results obtained to show that, 82% of geomagnetic storms occur at Dst≤ -100 nT level , about 12% are great GMS ,and about 6% are SGMS. It was also observed that 27% of geomagnetic storm occur during ascending phases of the SC and 73% of GMS occur during descending phase of the SC. Rodger C.J. et al.[9], this paper gives historical data of super geomagnetic storm of the last 50 years from 1965 to 2015. It is clear that solar cycle disrupt the geomagnetic field here we referred to the solar earth connection when high intensity and super geomagnetic storm occur the magnetic field based systems on the earth are affected. Gupta et al.[5] solar- terrestrial events and solar cycle phases were studied in this paper during 1956 to 1963, these events occur in the ascending and descending phases except at solar peak. Zang et al. [10] study the Solar terrestrial connection and GMSs are influenced by the combined impact of solar wind and IMF parameter. Katus R. M. et al. [6] in this paper investigate effect of geomagnetic storm on space based function.

This paper analyze super geomagnetic storm after statistical analysis we provide for the period 1964 to 2019 the maximum SGMSs are obtained between the time interval 19 UT to 6 UT (1^{st}+ 4^{th} quarter) the above time interval will be sensitive and important for task involving magnetic field (TIMF).

Data Analysis –

We have analyzed large GMS with the Dst values below -300 nanoteslas focusing on the period 1964-2019 that covers SC 20, 21, 22 ,23,and 24.Our research work used Dst values from the WDC at kyoto univ.

Table [1] :The SGMSs find during 1964 to 2019

Date	Time (UT)	Dst Value (nT)
Solar Cycle- 20 (1964 to 1976)		
25/05/1967	24UT	-312
26/05/1967	01UT	-317
26/05/1967	02UT	-383
26/05/1967	03UT	-377
26/05/1967	04UT	-383
26/05/1967	05UT	-387
26/05/1967	06UT	-350
26/05/1967	07UT	-342
Solar Cycle -21 (1976 to 1986)		
13/04/1981	07UT	-311
14/07/1982	02UT	-325
14/07/1982	03UT	-311
14/07/1982	04UT	-313
14/07/1982	05UT	-309
Solar Cycle- 22 (1986 to1996)		
13/03/1989	21UT	-302
13/03/1989	22UT	-382
13/03/1989	23UT	-418
13/03/1989	24UT	-472

14/03/1989	01UT	-583
14/03/1989	02UT	-589
14/03/1989	03UT	-463
14/03/1989	04UT	-386
14/03/1989	05UT	-346
14/03/1989	06UT	-343
09/11/1991	02UT	-354
09/11/1991	03UT	-350
09/11/1991	04UT	-330
09/11/1991	05UT	-324
09/11/1991	06UT	-303
Solar Cycle- 23 (1996 to 2008)		
16/07/2000	01UT	-301
16/07/2000	02UT	-301
31/03/2001	09UT	-387
31/03/2001	10UT	-346
31/03/2001	11UT	-317
21/11/2003	1UT	-309
08/11/2004	05UT	-342
08/11/2004	06UT	-368
08/11/2004	07UT	-374
08/11/2004	08UT	-343
08/11/2004	09UT	-320
29/10/2003	24UT	-350
30/10/2023	01UT	-353
30/10/2023	02UT	-341
30/10/2023	03UT	-335
30/10/2023	04UT	-303
30/10/2023	22UT	-316
30/10/2023	23UT	-383
30/10/2023	24UT	-371
31/10/2003	01UT	-307
20/11/2003	18UT	-329
20/11/2003	19UT	-396
20/11/2003	20UT	-413
20/11/2003	21UT	-422
20/11/2003	22UT	-422
20/11/2003	23UT	-405
20/11/2003	24UT	-343

Table [2] : Number of SGMSs (Dst≤-300nT) in different quarter of day

Time Interval	Number of SGMSs	Ratio
01UT – 06UT (QT.-1st)	31	55.35%
07UT – 12UT (QT.-2nd)	08	14.54%
13UT – 18UT (QT.-3rd)	01	01.81%
19UT – 24UT (QT.-4th)	15	27.27%

Table [3]: Number of SGMSs (Dst ≤-300nT) for SC 20-24 (In different quarter of day)

Solar Cycle Number	Number of SGMS in (19UT -06UT) ($1^{st}+4^{th}$ quarter)	Number of SGMS in (07UT -24UT) ($2^{nd}+3^{rd}$ quarter)	Number of SGMS in (01UT -24UT)	Ratio in ($1^{st}+4^{th}$ quarter)	Ratio in ($2^{nd}+3^{rd}$ quarter)
20	07	01	08	87.5%	12.5%
21	05	01	06	83.3%	16.7%
22	15	00	15	100%	0%
23	20	07	27	74.0%	26%
24	00	00	00	-	-

Table [4]: Monthly Variability of Super Geomagnetic Storms across Different Quarters-

Months	Number of SGMS in 19UT-06UT ($1^{st}+4^{th}$ quarter)	Number of SGMS in 07UT-18UT ($2^{nd}+3^{rd}$ quarter)
January	00	00
February	00	00
March	10	03
April	00	01
May	07	01
June	00	00
July	06	00
August	00	00
September	00	00
October	09	00
November	14	04
December	00	00

Table [1] shows the total number of SGMSs for the time interval 1 UT to 24 UT for the time period 1964 to 2019, a total of 55. Table [2] shows the values of individual SGMS for the time interval 7 UT to 18 UT and time interval 19 UT to 6 UT for the time period 1964 to 2019. Table [3] shows the SGMSs for the time interval 7 UT to 18 UT and 19 UT to 6 UT for solar cycles 20, 21, 22, 23, and 24. Table [4] represent monthly variability of super geomagnetic storms across different quarters 1^{st},2^{nd}, 3^{rd} and 4^{th}.

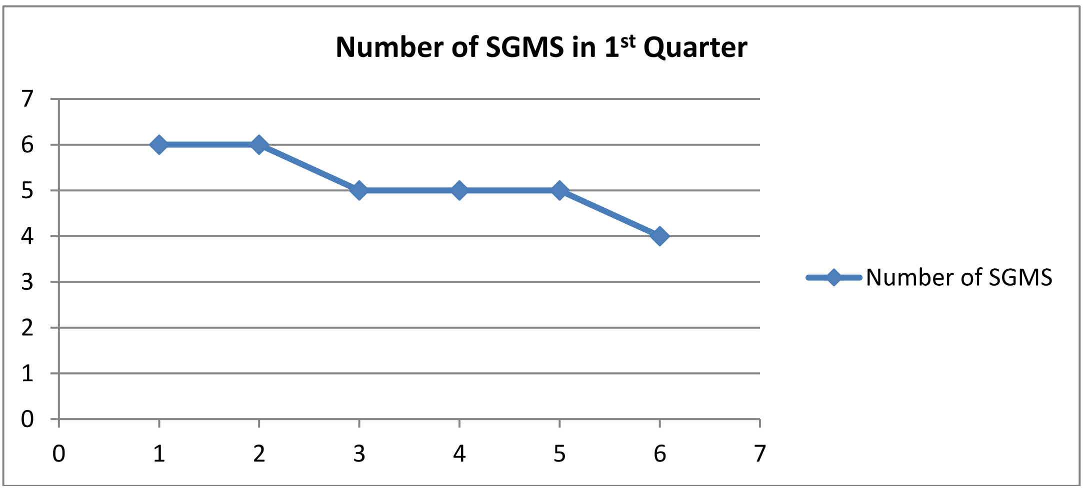

Figure [1] Distribution of SGMS in 1^{st} Quarter

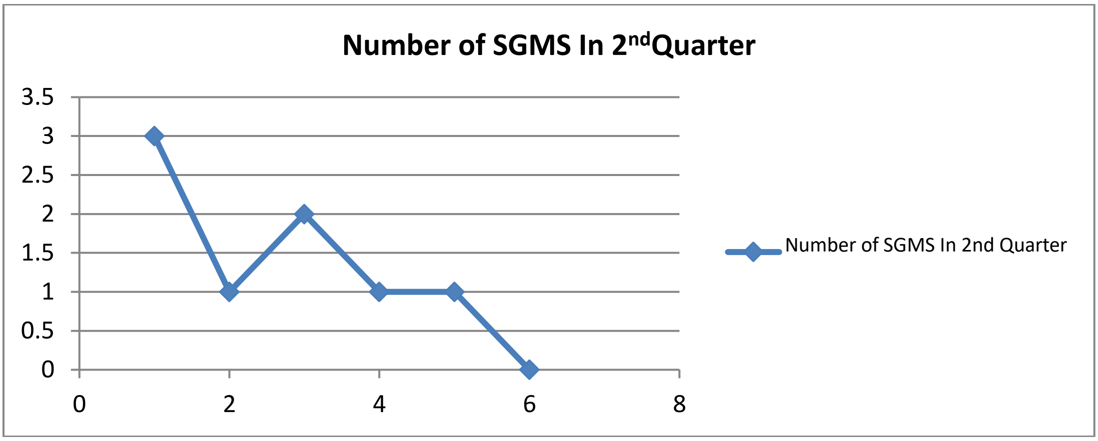

Figure [2] Distribution of SGMS in 2nd Quarter.

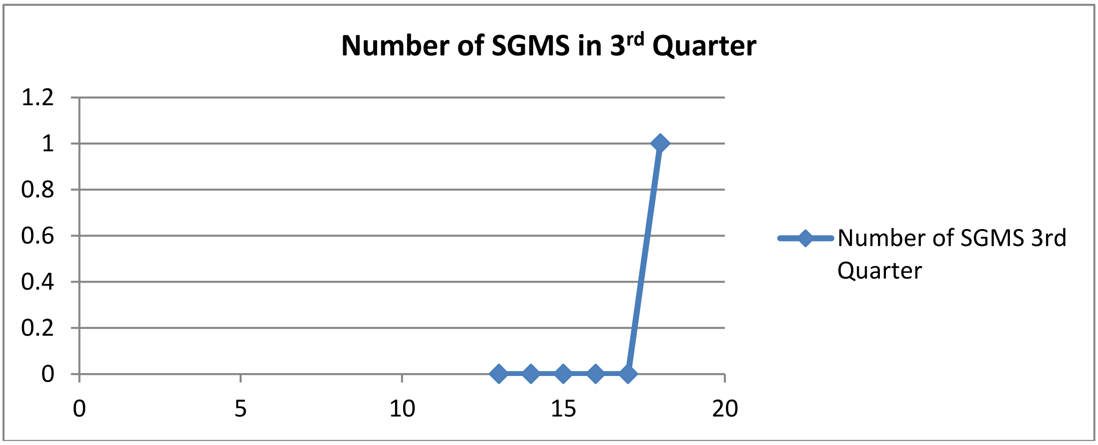

Figure [3] Distribution of SGMS in 3rd Quarter

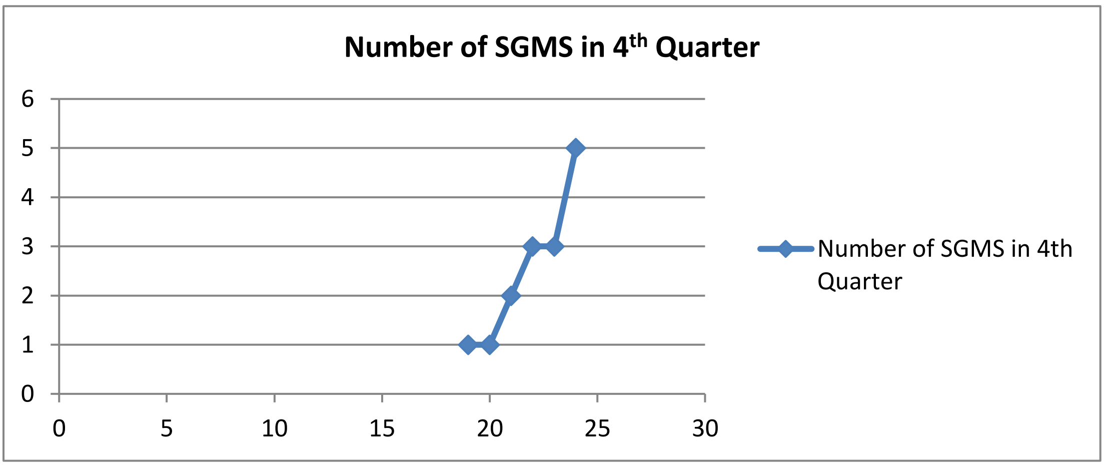

Figure [4] Distribution of SGMS in 4th Quarter.

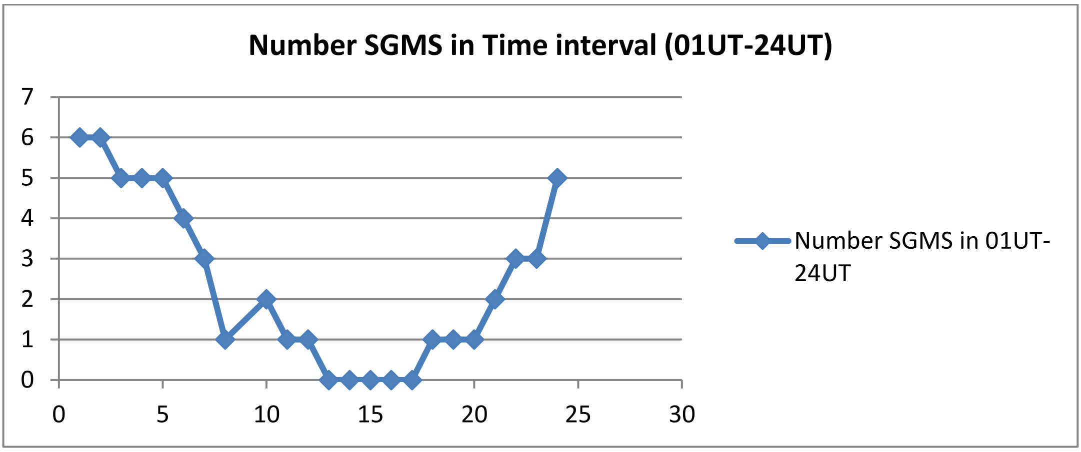

Figure [5] Distribution of SGMS in the (01UT-24UT) Time Interval

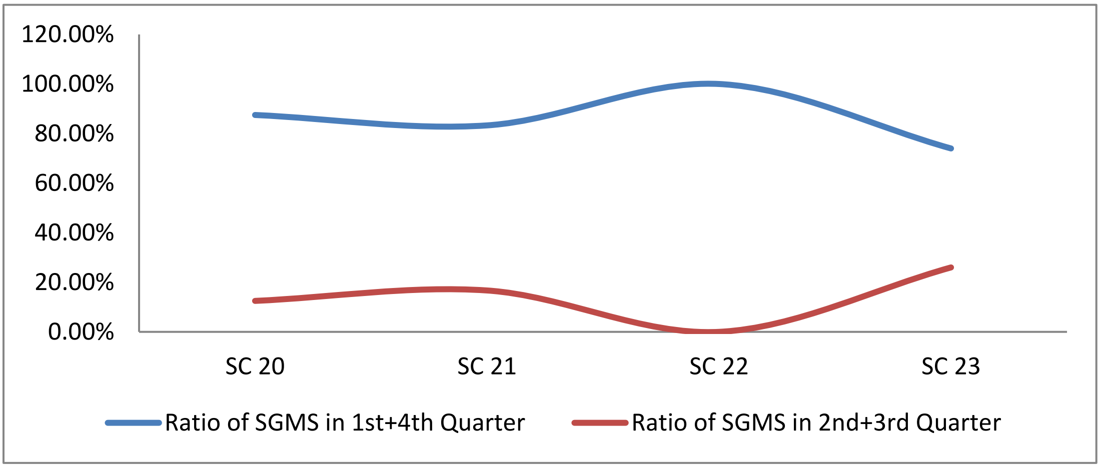

Figure [6] Ratio of SGMS for SC (20-24) in Different Quarters.

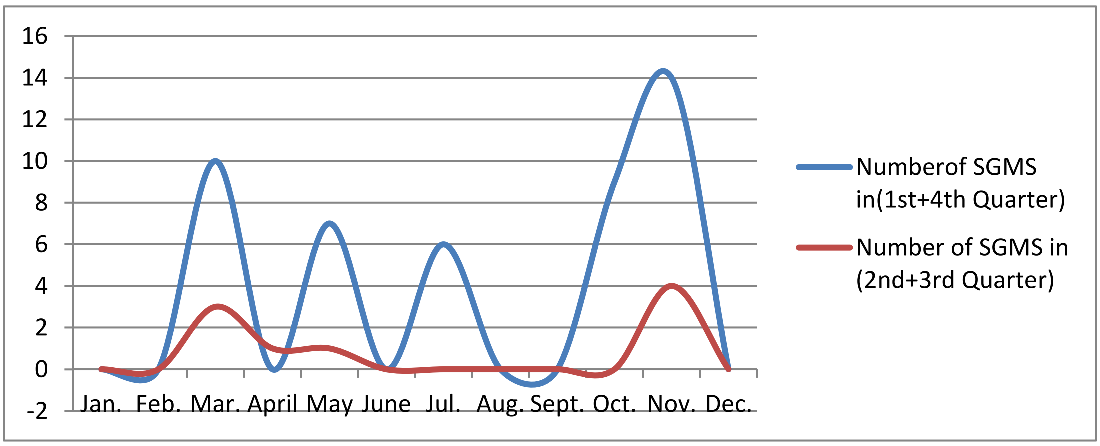

Figure [7] Monthly Variability of Super Geomagnetic Storms across Different Quarters

A comprehensive temporal analysis of Super Geomagnetic Storms (SGMS) reveals a pronounced non-uniformity in their distribution, characterized by a significant disparity in occurrence rates between the crepuscular hours (01-06 UT and 19-24 UT) and the intermediate hours (07-12 UT and 13-18 UT). Specifically, the first and fourth quarters exhibit a combined total of 46 SGMS (82.14%), whereas the second and third quarters yield a mere 9 SGMS (16.1%), underscoring the heightened sensitivity of the former to SGMS. Seasonal variability analysis reveals a marked predilection for SGMS occurrence during the months of March, May, October, and November, with the highest frequencies observed in March and November. Quarter-wise analysis reveals a complex pattern of SGMS occurrence, characterized by an initial spike is followed by a drop during first quarter, a monotonic increase during fourth quarter, also a non-monotonic variation in the second quarter. Notably, SGMS occurrence is exclusively confined to 18 UT in the third quarter. Solar cycle analysis reveals a pronounced variability in SGMS occurrence rates, with Solar Cycles 20 and 21 exhibiting a solitary SGMS in the second and third quarters, whereas Solar Cycle 22 yields 15 SGMS exclusively in the first and fourth quarters. Solar Cycle 23 produces 20 SGMS in the first and fourth quarters and 7 SGMS in the second and third quarters. Solar Cycle 24 exhibits a null SGMS occurrence. These findings underscore the complex interplay between diel, seasonal, and solar cycle variability in modulating SGMS occurrence, with significant implications for our understanding of the underlying physical mechanisms governing SGMS dynamics.

A comparative analysis of the four quarters reveals a significant disparity in the number of Super Geomagnetic Storms (SGMS). The first quarter exhibits the highest frequency, with 31 SGMS, whereas the third quarter records the lowest, with only 1 SGMS. This stark contrast indicates that the first quarter poses a greater risk to the Earth's magnetic field, making it a more hazardous period for geomagnetic disturbances and space weather events. A comparative analysis of Solar Cycles 20-24 reveals distinct quarter-wise distributions of Super Geomagnetic Storms (SGMS). In the first and fourth quarters, Solar Cycle 22 exhibits the highest SGMS frequency (100%), while Solar Cycle 23 shows the lowest (74%). Conversely, in the second and third quarters, Solar Cycle 23 records the highest SGMS frequency (26%), whereas Solar Cycle 22 shows no SGMS activity (0%). Notably, Solar Cycle 24 exhibits no SGMS activity across all quarters.

Result and Discussion -

1] A comprehensive analysis of Super Geomagnetic Storms (SGMS) spanning 1964-2019 revealed a total of 55 events within the 1 UT to 24 UT time intervals.

[2] Notably, only 9 SGMS (16.1%) occurred during the 07 UT to 18 UT interval , encompassing the second and third quarters of the day.

[3] In stark contrast, the 19 UT to 06 UT interval (encompassing the first and fourth quarters) witnessed a significantly higher frequency of SGMS, with 46 events (82.14%) recorded during this time.

[4] A solar cycle-wise breakdown revealed the following SGMS distributions:

* Solar Cycle 20: 1 SGMS (07-18 UT), 7 SGMS (19-06 UT), percentage: 87.5%

* Solar Cycle 21: 1 SGMS (07-18 UT), 5 SGMS (19-06 UT), percentage: 83.3%

* Solar Cycle 22: 0 SGMS (07-18 UT), 15 SGMS (19-06 UT), percentage: 100%

* Solar Cycle 23: 7 SGMS (07-18 UT), 20 SGMS (19-06 UT), percentage: 74.0%

* Solar Cycle 24: 0 SGMS (07-18 UT), 0 SGMS (19-06 UT)

These findings unequivocally demonstrate the heightened sensitivity and risk associated with the 19 UT to 06 UT interval for Tasks Involving Magnetic Fields (TIMF).

[5] A monthly analysis of SGMS frequency within the 19 UT to 06 UT ($1^{st}+4^{th}$ quarter) interval revealed the following distributions- March: 10 SGMS, May: 7 SGMS, July: 6 SGMS, October: 9 SGMS, November: 14 SGMS and no SGMS were recorded in the remaining months.

[6] In contrast, the 07 UT to 18 UT ($2^{nd}+3^{rd}$ quarter) intervals exhibited a significantly lower SGMS frequency, with only 9 events recorded- November: 14 SGMS, March: 3 SGMS, April: 1 SGMS, May: 1 SGMS, November: 4 SGMS and no SGMS were recorded in the remaining months.

Conclusion -

This comprehensive statistical analysis of Super Geomagnetic Storms (SGMS) between the time period 1964 to 2019, it has been found that 16.1% SGMS are obtained between the time interval 7UT to 18UT ($2^{nd}+3^{rd}$ quarter) and 82.14% SGMS are obtained between the time interval 19UT to 6UT ($1^{st}+4^{th}$ quarter). The time interval 19UT to 6UT will be sensitive and dangerous for Task Involve Magnetic Field (TIMF) such as GPS, satellite launching, navigation, radio communication, power system, and directional drilling etc. If TIMF is performed between the time intervals 19UT to 06UT around the peak of the solar cycle, then the results will be affected. A monthly analysis of Super Geomagnetic Storms (SGMS) reveals quarter-wise variations. In the first and fourth quarters, March exhibits the highest SGMS frequency (10 events), while January, February, April, June, August, September, and December record no SGMS activity. Similarly, in the second and third quarters, November shows the highest SGMS frequency (4 events), whereas jan., feb., june, july, aug., sept., oct., and dec. exhibit no SGMS activity. This analysis identifies the months with zero SGMS events as the safest periods for the TIMF.

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